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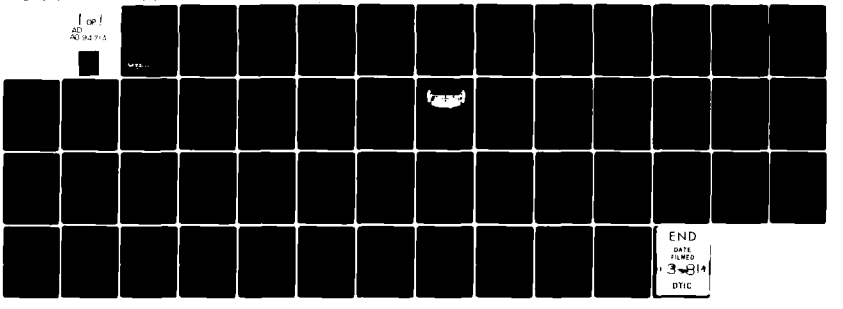

FCR-2834

OPTIMIZATION OF CARBON-SUPPORTED PLATINUM CATALYSTS FOR FUEL CELL ELECTRODES

Contract No. DAAK70-79-C-0151

October 1979 to October 1980

Final Technical Report

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Prepared for

U.S. Army Mobility Equipment Research and Development Command
Fort Belvoir, VA 22060

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The views, opinions, and/or findings contained in this report are those of the authors and shall not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

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The objective of this program was to optimize electrodes using the carbon-supported platinum catalysts at the operating conditions required for use in methanol-air, phosphoric-acid electrolyte, fuel cell power plants for U.S. Army applications.

Cathodes using proprietary, supported-platinum catalyst, GSA-6, were fabricated with various degrees of hydrophobicity by adjusting the Teflon® content in the catalyst layer and by changing the Teflon sintering cycle. These cathodes were tested with supported-platinum anodes in eighteen subscale cells at the Army power plant operating conditions for periods exceeding 5000 hours. The optimum structure, on the basis of peak cell voltage, endurance stability, and manufacturing reproducibility was found to be one containing 47.5% Teflon. A standard United proprietary anode catalyst showed satisfactory peak performance and

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endurance stability. The cells with optimized electrodes exceeded the program 500-hour performance goal of 0.620V at 200 mA/cm^2 by 0.020V. The 6000-hour performance goal of 0.590 V at 200 mA/cm^2 was projected to be exceeded by 0.036 to 0.038 V (based on over 4000 hours of operation).

Six three-cell stacks incorporating the optimized electrodes and ten sets of optimized electrodes for subscale cell testing were fabricated and delivered to the U. S. Army Mobility Equipment Research and Development Command (MERADCOM) at Fort Belvoir, Virginia.

SUMMARY

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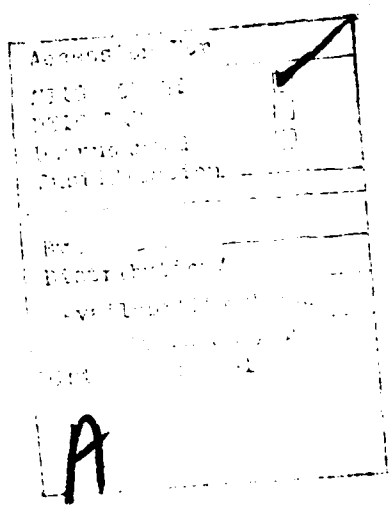

PREFACE

This report is the final technical report on Contract No. DAAK70-79-C-0151 between the U. S. Army Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Virginia and Power Systems Division of United Technologies Corporation (United), South Windsor, Connecticut. The work reported here was conducted from October 1979 to October 1980. The contributions of Dr. J. A. Joebstl, the MERADCOM technical representative, are grately acknowledged. Technical contributors to this program at United included F. J. Luczak, H. R. Kunz, R. D. Coykendall, D. A. Landsman, G. A. Gruver, J. V. Congdon, R. D. Breault, R. W. Fahle, and A. J. DeCasperis.

CONTENTS

INTRODUCTION

The objective of this 13-month contract was to optimize the performance and endurance of state-of-the-art fuel cell electrodes incorporating carbon-supported platinum catalysts for use in a methanol-air, phosphoric acid fuel cell for U. S. Army application. Cathodes were optimized for the reduction of oxygen (O_2) in air and anodes for the oxidation of hydrogen (H_2) in methanol-derived reformer gas. Performance testing of the optimized electrodes was carried out in subscale, 2-in. x 2-in. phosphoric acid fuel cells at the operating conditions and gas compositions specified in the contract for times up to 5000 hours. At the conclusion of the optimization and testing portions of the contract, the optimized electrodes were incorporated into six full-size, three-cell stacks which were delivered to MERADCOM. In addition, ten sets of 2-in. x 2-in. optimized electrodes were supplied to MERADCOM for testing. All electrodes were made to United's ribbed-substrate electrode design, incorporating appropriate acid storage capacity.

During the course of the electrode optimization and subscale cell testing, certain cell performance levels were required and all cell performance goals were either met or exceeded. These included a minimum cell terminal voltage of 0.620 V at 200 mA/cm^2 at 500 hours of operation and a minimum cell terminal voltage of 0.590 V at 200 mA/cm^2 at 6000 hours of operation (performance could be extrapolated to 6000 hours). The cell operating conditions required are listed in Table 1 where gas C is the approximate methanol-derived reformer gas specified to be used as fuel.

Contract requirements were fulfilled by organizing the program into four tasks:

Task 1 Electrode Optimization for Subscale Cell Tests
Task 2 Subscale Cell Testing
Task 3 Electrode and Stack Fabrication
Task 4 Program Reporting

TABLE 1. CELL OPERATING CONDITIONS

Cell Temperature:		357°F	
Cell Current:		186 ASF (200 mA/cm^2)	
Oxidant:		Air (25% O_2 utilization)	
Fuel (Vol %):	Gas A	Gas B	Gas C
	73.6% H_2 1.6% CO 17.3% CO_2 7.5% H_2O	64.7% H_2 1.0% CO 26.8% CO_2 7.5% H_2O	69.3% H_2 1.0% CO 22.2% CO_2 7.5% H_2O
H_2 Utilization:		75%	

INVESTIGATION AND DISCUSSION

TASK 1 ELECTRODE FABRICATION AND OPTIMIZATION

When a fuel cell catalyst is incorporated into Teflon®-bonded, gas-diffusion electrodes of constant metal loading per unit electrode area, the achievable performance levels and the stability of these performance levels with time are both controlled, in large part, by the electrode wetting characteristics. A compromise between high performance and performance stability can be achieved by ensuring that the electrode has adequate, but not excessive, hydrophobicity. Excessive hydrophobicity results in poor electrolyte filling of the electrode, poor catalyst utilization, and a high resistance to ionic migration within the electrode. Inadequate hydrophobicity results in a "flooded" electrode with high gas-phase reactant diffusional losses. With United's state-of-the-art phosphoric acid fuel cell electrodes, proper electrode hydrophobicity is achieved by controlling both the amount of Teflon in the catalyst layer and Teflon heat-treatment cycle (time and temperature). These two factors were the variables studied to optimize cathode performance and performance stability for the specified operating conditions. All anodes and cathodes tested in the program had nominal platinum loadings of 0.25 mg/cm^2 and 0.50 mg/cm^2, respectively.

Two of United's standard 3.7-ft^2 electrodes were chosen as baseline electrodes in the optimization program. The anode chosen was the NOCAN™ anode which was developed and fabricated for use in the 4.8-MW Demonstrator power plant being constructed in New York City by Consolidated Edison Incorporated under contract with the Department of Energy and the Electric Power Research Institute. The cathode catalyst chosen was United's advanced GSA-6 platinum catalyst. Both 3.7-ft^2 electrodes were fabricated in the electrode production facility using standard materials and procedures. The Teflon content in the cathode catalyst layer was 47.5 wt.%. Before the Teflon sintering cycle was performed on the cathode, the electrode was divided into several pieces. The hydrophobicity of these cathode pieces was varied by subjecting them to different oven-belt speed cycles. One piece was subjected to the "standard" belt speed (subsequently designated "medium" speed). One piece was rendered less hydrophobic than the

standard (designated "fast" speed), and another piece was rendered more hydrophobic than the standard (designated "slow" speed). The anode was sintered using a standard anode sinter cycle. The current-collecting substrates of all the electrode samples were then "ribbed" to provide gas channels, silicon carbide matrices were applied, and the electrodes were submitted for 2-in. x 2-in. subscale, 500-hour performance testing (Cells 3403, 3404, and 3405).

The 47.5 wt.% Teflon used in the cathode catalyst layer described above was previously found by United to give optimum cathode performance characteristics for the 4.8-MW application which involves operation at 190°C, somewhat above the 180°C operating temperature of the MERADCOM application. Adequate hydrophobicity with higher performance at the lower operating temperature might be achieved with a lower Teflon content in the catalyst layer. Therefore, another 3.7-ft^2 cathode was fabricated from GSA-6 catalyst, but using 40 wt.% Teflon instead of the 47.5 wt.%. Again the electrode was cut into pieces before the Teflon sintering cycle. Three of the cathode pieces were subjected to the same belt-speed cycles previously described for the 47.5 wt.% Teflon electrodes. A fourth piece was subjected to an additional cycle (subsequently designated "very slow") to impart additional hydrophobicity. All other materials and procedures were the same as those used for the 47.5 wt.% Teflon cathodes. These cathodes were then submitted with standard anodes for 2-in. x 2-in. subscale cell, 500-hour performance testing (Cells 3406, 3407, 3408, and 3409). (Note: It will be shown in a later section of this report that the standard NOCAN anode gave very close to optimum performance at the MERADCOM conditions. Hence, no additional anode optimization was necessary to meet the program goals.)

Four cathodes were also fabricated in the laboratory using 40% Teflon in the catalyst layer to compare with the 40% Teflon cathodes produced in United's semi-production facility. Although the laboratory catalyst layer fabrication procedures were different than those used in the production facility, the materials used were identical and the Teflon sintering cycle was held constant by sintering the electrodes in the production oven using the same four belt-speed sinter cycles on the laboratory electrodes as previously described. These laboratory cathodes were

also submitted with standard anodes for 2-in. x 2-in. subscale cell 500-hour performance testing (Cells 3412, 3413, 3414, and 3415).

At the conclusion of the electrode optimization and 500-hour performance testing tasks, additional optimized electrodes were fabricated and submitted for 2-in. x 2-in. subscale testing for evaluating reproducibility of performance and long-term endurance.

TASK 2 SUBSCALE CELL PERFORMANCE TESTING

All cell performance testing was done in subscale 2-in. x 2-in. cells using electrodes and matrices prefilled with the appropriate amount of phosphoric acid prior to assembling them in the test hardware. The cells were tested under conditions of resistive loading on United's automated endurance test stand facilities. Cell performance was continuously monitored and periodically stored in a computerized data base. Table 1 shows three fuel compositions: gas C is the approximate composition of fuel expected to result from reformed methanol; gases A and B are fuel gas mixes which were used as the anode fuels in the subscale cell testing since they approximate gas C and were readily available.

The short-term initial performance screening tests were run for at least 500 hours. In addition to running at constant load at the operating conditions listed in Table 1, diagnostic polarization tests were performed on the cells at startup and at 500 hours to determine the source of any performance losses. Cathode diagnostics were obtained by running the cell alternately on oxygen and air (low utilization) with the anode operating on pure hydrogen (low utilization). Cell performance was measured as a function of load current, with the difference between oxygen and air performance designated "oxygen gain." Cell internal resistance was automatically measured by current-interruptor techniques and performance was appropriately corrected for this. These data were helpful in identifying cathode deficiencies and allowed an assessment of factors such as catalyst activity and degree of hydrophobicity. Anodes were evaluated by measuring the change in cell voltage when the fuel was changed from simulated reformed methanol to pure hydrogen (designated "hydrogen gain").

Cell performance data with time for the operating conditions listed in Table 1 are shown in Appendix A for each cell tested. The cell voltages plotted are terminal voltages corrected only by a small factor which is added to the terminal voltage. This small factor takes into account the slightly higher iR contributed by the thick subscale plates compared to the iR of thinner production-type separator plates and the slightly higher iR contributed by overly-thick matrices. This correction factor varied from -1 mV to 21 mV.

Cell diagnostic data are tabulated in Appendix B for all cells tested.

Optimized electrodes were also tested in 2-in. x 2-in. subscale cells to determine if they would meet the 6000-hour (projected) performance goal. These cells ran for times exceeding 4000 and 5000 hours with diagnostic data acquired every 1000 hours.

Results of Electrode Optimization and Subscale Cell Testing

Table 2 contains a summary of cathode descriptions and performance characteristics for each of the eighteen subscale cell tests run during the course of the program. A plot of the performance history for each of these cells can be found in Appendix A. A summary of diagnostic data acquired for each of these cells can be found in Appendix B.

47.5% Teflon Cathodes - All of the first three cells with the 47.5% Teflon cathodes and standard anodes (Cells 3403, 3404, and 3405) easily exceeded the 500-hour performance goal of 0.620 V at 186 ASF (200 mA/cm^2). The maximum cell voltage achieved was inversely related to the hydrophobicity of the cathode in this series (see Table 2). The hydrogen gains for these anodes were 17 to 21mV (see Table B-1, Appendix B) which is such a small polarization loss that this anode was considered so close to optimum that no meaningful program could be performed to improve the performance of anodes for operating at these conditions. For this reason, no additional anode optimization was done in this program, and all anodes used or delivered in this program were standard anodes.

40% Teflon Cathodes - The four cells with the 40% Teflon cathodes were then tested for slightly over 500 hours (Cells 3406, 3407, 3408, and 3409). The relationship between cell performance and relative hydrophobicity was found to be the same as in the case of the 47.5% Teflon cathodes (i.e., the least hydrophobic cathode gave highest cell performance) even though the performance level of these cells was considerably lower than anticipated. These lower performances resulted from lower cathode activity, higher cell resistances, and higher cathode internal resistances.

TABLE 2. SUMMARY OF CELLS TESTED

CELL NO.	CATHODE TEFLON CONTENT, %	SINTER CYCLE	OPERATING CONDITIONS (a)	MAX. CELL VOLTAGE, V (b)	TIME MAX. VOLTAGE, h	SHUTDOWN VOLTAGE, V	OPERATING TIME, h (c)
3403	47.5	Slow	Gas B	0.644	162	0.636	833
3404	47.5	Medium	Gas B	0.646	64	0.629	882
3405	47.5	Fast	Gas B	0.655	39	0.639	858
3406	40	Very Slow	Gas B	0.604	543	0.604	554
3407	40	Slow	Gas B	0.613	543	0.613	554
3408	40	Medium	Gas B	0.621	544	0.621	554
3409	40	Fast	Gas B	0.624	545	0.624	556
3412	40 (e)	Very Slow	Gas A	0.628	67	0.618	862
3413	40 (e)	Slow	Gas A	0.636	163	0.633	693
3414	40 (e)	Medium	Gas A	0.634	206	0.625	688
3415	40 (e)	Fast	Gas A	0.657	17	0.636	667
3418	47.5	Slow	Gas A, B	0.652	950	0.640	5310(d)
3419	47.5	Slow	Gas A, B	0.625	2150	0.611	5310(d)
3420	47.5	Slow	Gas A	0.593	570	0.593	764
3421	47.5	Slow	Gas A	0.631	326	0.631	328
3422	47.5	Slow	Gas A	0.616	256	0.616	328
3423	47.5	Medium	Gas A, B	0.644	1075	0.634	4350(d)
3424	47.5	Medium	Gas A, B	0.647	1075	0.632	4350(d)

NOTES: (a) See Table 1 for conditions and fuel compositions.
(b) Corrected for thick-plate iR.
(c) All cell tests were terminated intentionally.
(d) Cells were still operating stably at program termination date.
(e) Catalyst layer prepared in laboratory

In addition, the performance histories for these cells show that performance in all cases was slowly increasing with time during the test period (see Appendix A). All of these data indicate overly-hydrophobic cathode catalyst layers which were slowly filling with time. Two of these cells did meet the 500-hour performance goal of 0.620 V, but all of the cells were still increasing in performance at the end of the test period.

Laboratory 40% Teflon Cathodes - The most likely reason for the surprising hydrophobicity of the 40% Teflon cathodes was associated with the procedures used to produce the catalyst-Teflon mixtures. Only a small amount of this mixture was needed for the 40% Teflon electrodes whereas large process quantities are used at the 47.5% level since this is a standard mixture. To better control this mixture, a second run of 40% Teflon electrodes was fabricated in the laboratory, but with belt-sintering done in the production oven. These cathodes were then tested in subscale cells (Cells 3412, 3413, 3414, and 3415). These cells performed better than the previous cells with the 40% Teflon electrodes, and all of them exceeded the 500-hour performance goal.

Optimum Performance (Short-term) - In order to determine the optimum electrode for long-term endurance and stack fabrication, a graph of peak cell performance as a function of cathode sintering cycle was prepared as shown in Figure 1. On the average, the 47.5% Teflon cathodes gave the best cell performance. When performance stability was considered in addition to peak performance, the 47.5% cathode with the longest sintering time (designated "slow") was considered to be the best choice for use in the long-term cell tests (i.e., the cathode used in Cell 3403).

Long-term Cell Testing - Three long-term endurance cells which had cathodes of the type used in Cell 3403 were tested (Cells 3418, 3419, and 3420). These cells gave widely varying performances. Once again, a comparison of diagnostic data (Tables B-4 and B-5, Appendix B) and performance history characteristics for these cells (Appendix A) indicates that differing degrees of hydrophobicity is the reason for lack of performance reproducibility. Yet all of these cathodes (including the one in Cell 3403) had been cut from the same 3.7-ft^2 electrode.

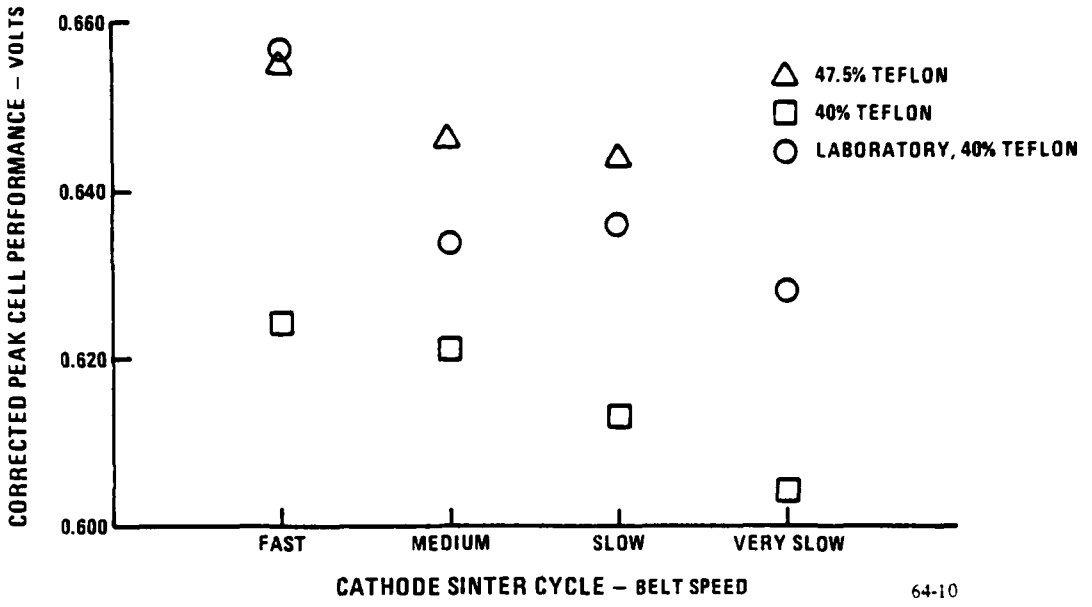

Figure 1. Peak Cell Performance vs. Cathode Sinter Cycle

Another 3.7-ft^2 electrode was fabricated using the same procedures. Two cells were tested with cathodes cut from this second large electrode (Cells 3421 and 3422). The performance histories (Appendix A) and diagnostic data (Table B-4, Appendix B) for these cells indicated that these cathodes were also too hydrophobic.

The results obtained with this type of cathode indicate that, although these cathodes will give stable performance and some give high performance, others will give moderate-to-low performance levels. In general, these cathodes are marginally too hydrophobic. For this reason, the optimum cathode for this application was redefined as a 47.5% Teflon cathode sintered at the "medium" belt-speed cycle (i.e., the cathode in Cell 3404). This is slightly less hydrophobic and will result in improved initial performance. A great deal of operating experience has been obtained with this type cathode because it was also found to be the optimum cathode for the 40-kW fuel cell power plant being developed by United in conjunction with the Department of Energy and the Gas Research Institute.

Two cells were started with the redefined optimum cathode for long-term endurance testing (Cells 3423 and 3424). In addition, the two best cells with the earlier "optimum" cathode were continued on endurance testing (Cells 3418 and 3419). Performance histories and diagnostic data for all these cells are given in Appendix A and B, respectively. The cells with the redefined optimum cathode (Cells 3423 and 3424) were operated for over 4300 hours and gave very good performance and performance stability. These cells clearly exceeded the 500-hour performance goal of 0.620 V at 200 mA/cm^2 (186 ASF), and simple linear extrapolation of their performance histories projects they would easily exceed the 6000-hour performance goals of 0.590 V at 200 mA/cm^2 (186 ASF) and 0.640 V at 100 mA/cm^2 (93 ASF). Cell performances projected to 6000 hours are presented in Table 3.

Anode Performance - As discussed earlier, the diagnostic data from the first three subscale cell tests using standard anodes indicated the anodes were operating very close to optimum performance. Anode diagnostic data on this type anode in all the other cell tests verified the initial conclusions.

The effect of fuel composition on cell performance can be seen by studying the performance histories for Cells 3418, 3419, 3423, and 3424. During the period of operation of these cells, the fuel provided to the cell endurance test facility was changed from gas A to gas B (see Table 1); gas C is the approximate composition expected from reformed methanol in the MERACOM application. Cell operation on gas A would be expected to give slightly higher performance than that on gas C, and gas B would be expected to give slightly lower performance than that on gas C. The effect on cell performance of switching from gas A to gas B was slight (only 7 to 8 mV lower performance) and demonstrates that cell operation on these fuels in no way compromised the achieved performance goals or the selection of the optimum performing electrodes.

It should also be noted that a shutdown/restart cycle was performed on Cells 3418, 3419, 3423, and 3424 resulting in no significant effect on cell performance.

TABLE 3. PROJECTED 6000-HOUR PERFORMANCE OF OPTIMIZED ELECTRODES

TYPE	CELL NO.	MAX. LOAD TIME, h	200 mA/cm² CELL VOLTAGE, V	200 mA/cm² 6000-HOUR CELL VOLTAGE (PROJECTED), V	100 mA/cm² CELL VOLTAGE, V	100 mA/cm² 6000-HOUR CELL VOLTAGE (PROJECTED), V
Preliminary	3418	5310	0.640	0.640	0.686	0.680
Optimized	3419	5310	0.611	0.610	0.675	0.669
Final	3423	4350	0.634	0.628	0.689	0.685
Optimized	3424	4350	0.632	0.626	0.691	0.682

TASK 3 ELECTRODE AND STACK FABRICATION

Electrode Fabrication

At the conclusion of the electrode optimization and testing program, optimized electrodes were fabricated in the electrode production facility to provide electrodes for subscale cell testing and for use in three-cell stacks for delivery to MERADCOM. For the subscale cells, ten 3-in. x 3-in. optimized anodes and ten 3-in. x 3-in. optimized cathodes were prepared (including matrix), packed, and shipped to MERADCOM.

Stack Fabrication

An additional program requirement was to design, fabricate, and deliver to MERADCOM six, three-cell fuel cell stacks incorporating the optimized electrodes identified in Tasks 1 and 2. The stacks were designed, fabricated and shipped to MERADCOM. The cell size and dimensions are similar to the cell being developed by United for the methanol-fueled 1.5-kW silent fuel cell under MERADCOM Contract DAAK70-80-C-0041.

Figure 2 shows one of the three-cell stack assemblies.

Cell Test Hardware

The contract was modified to include the fabrication and delivery to MERADCOM of two sets of United's 2-in. x 2-in. subscale cell test hardware.

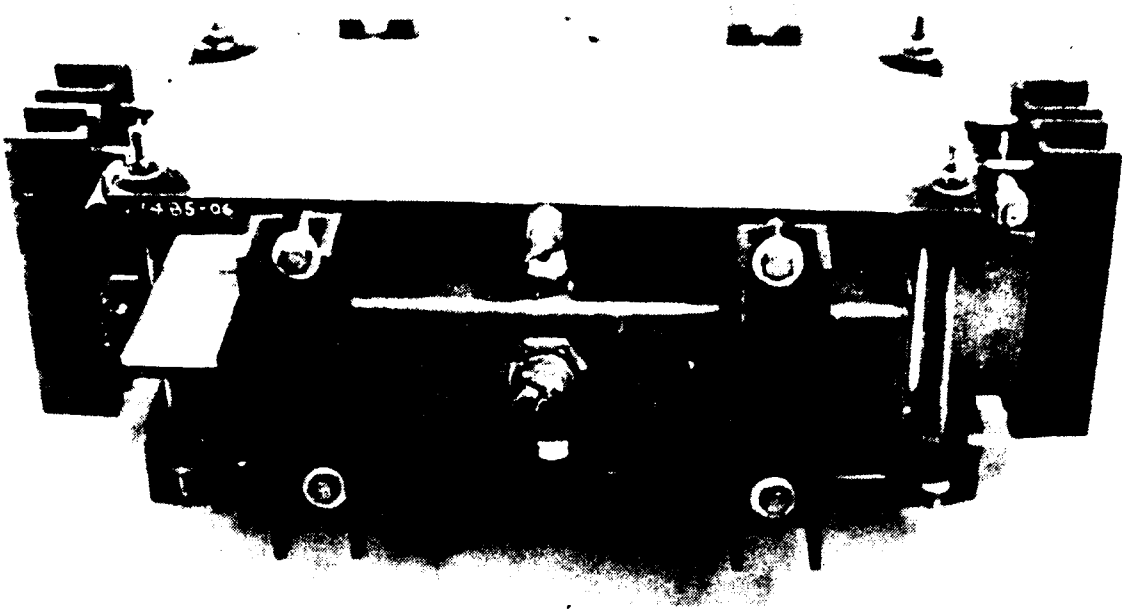

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Figure 2. Three-Cell Stack Assembly

CONCLUSIONS

Subscale cell testing has led to the identification of electrodes which give a good combination of reproducible high cell performance and good performance stability at the operating conditions required for the MERADCOM methanol-air phosphoric acid fuel cell application. These desirable performance characteristics were achieved mainly by optimizing cathode catalyst layer hydrophobicity. The optimum performing electrodes for this application are United's ribbed-substrate NOCAN anode and a ribbed-substrate cathode comprised of United's platinum GSA-6 catalyst and 47.5 wt.% Teflon. Subscale cells incorporating these electrodes gave performance which easily exceeded the program goals of 0.620 V at 200 mA/cm^2 after 500 hours of operation and 0.590 V at 200 mA/cm^2 after 6000 hours of operation. These electrodes fully met all the requirements of the program.

RECOMMENDATIONS

Although the electrodes optimized in this program easily met the performance and endurance goals, the capability of these electrodes to meet the requirements of an operational methanol-air power plant has not been confirmed. Additional experiments are needed to subject the electrodes to all of the operating conditions of the actual power plant. These include shutdown-restart cycles over a range of ambient temperatures.

APPENDIX A
PERFORMANCE HISTORY OF CELLS

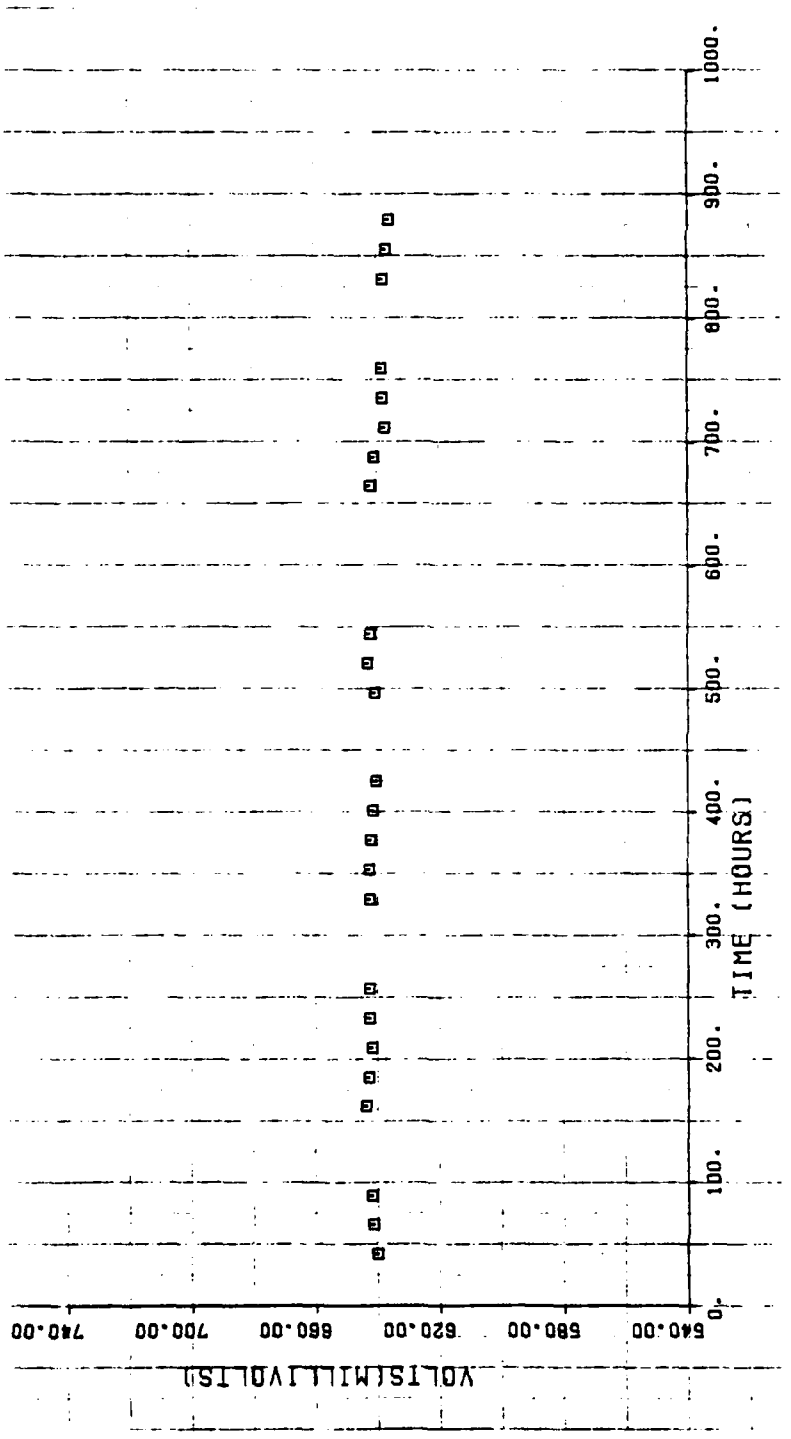


Figure A-1. Performance History of Cell 3403

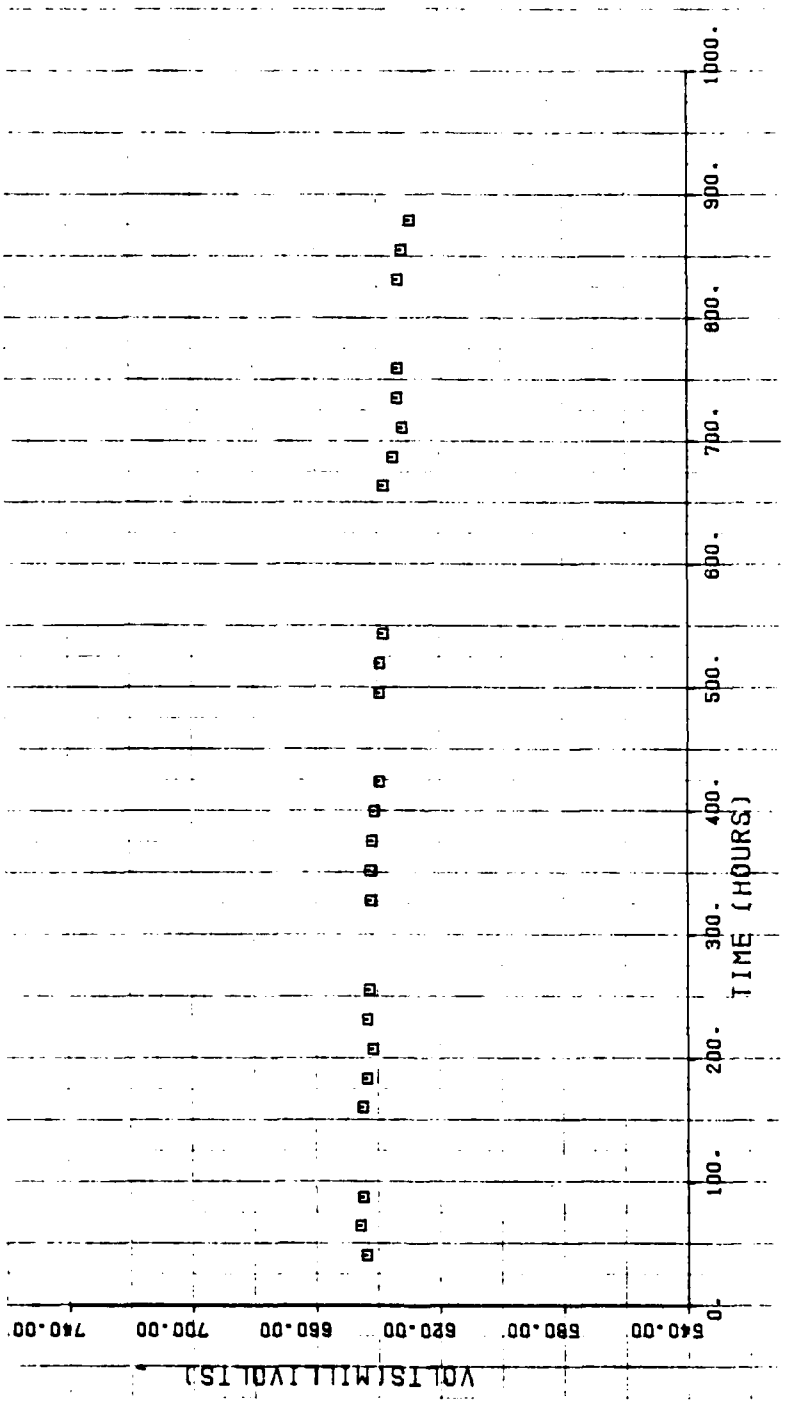


Figure A-2. Performance History of Cell 3404

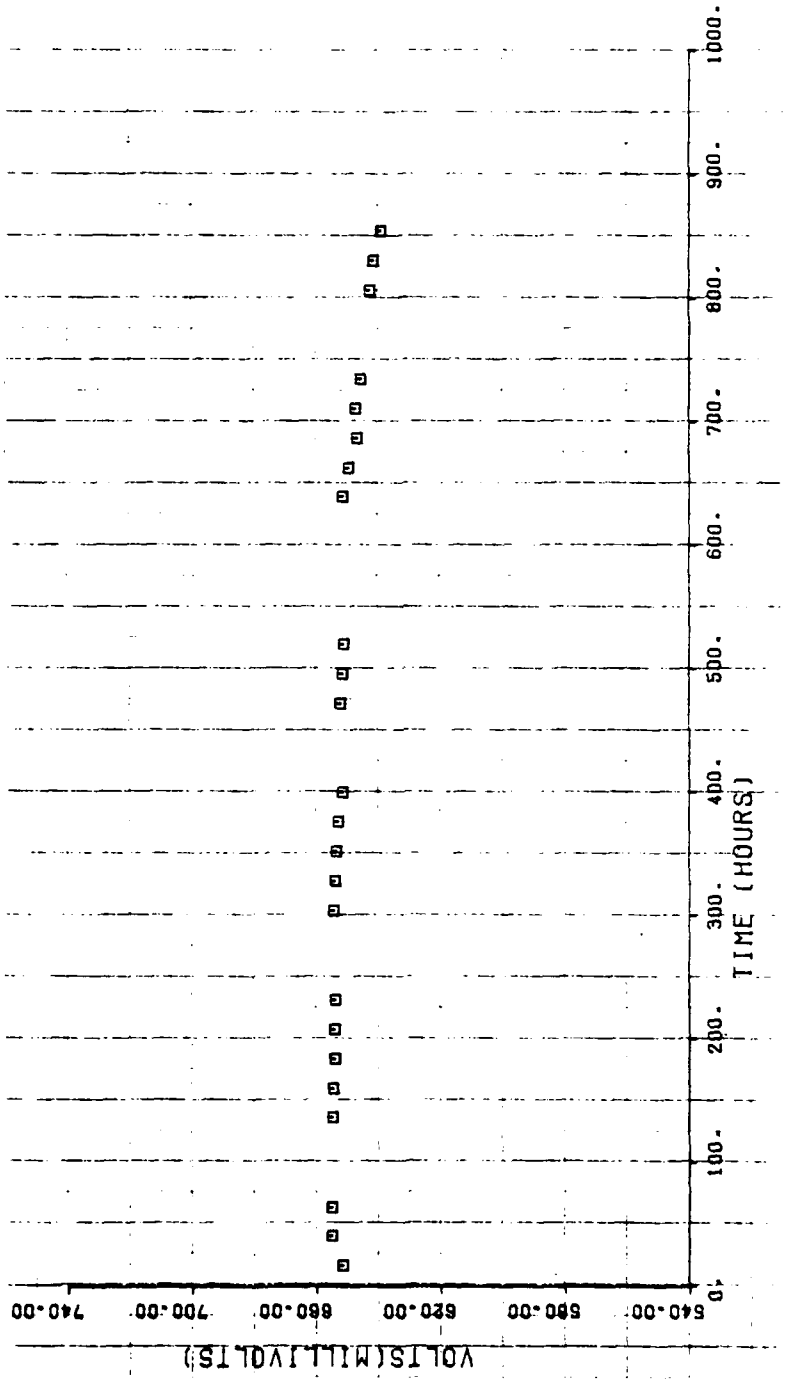


Figure A-3. Performance History of Cell 3405

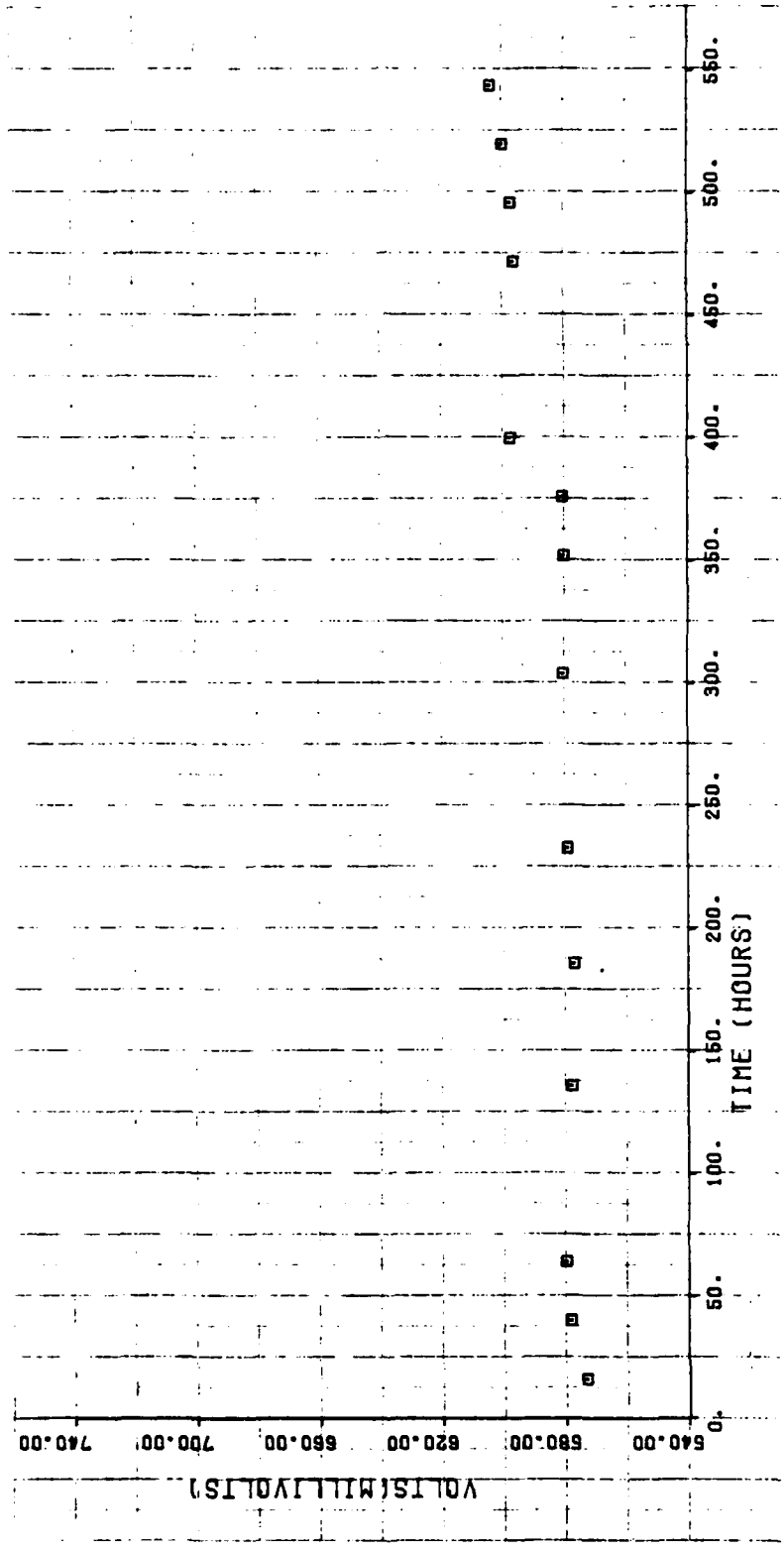
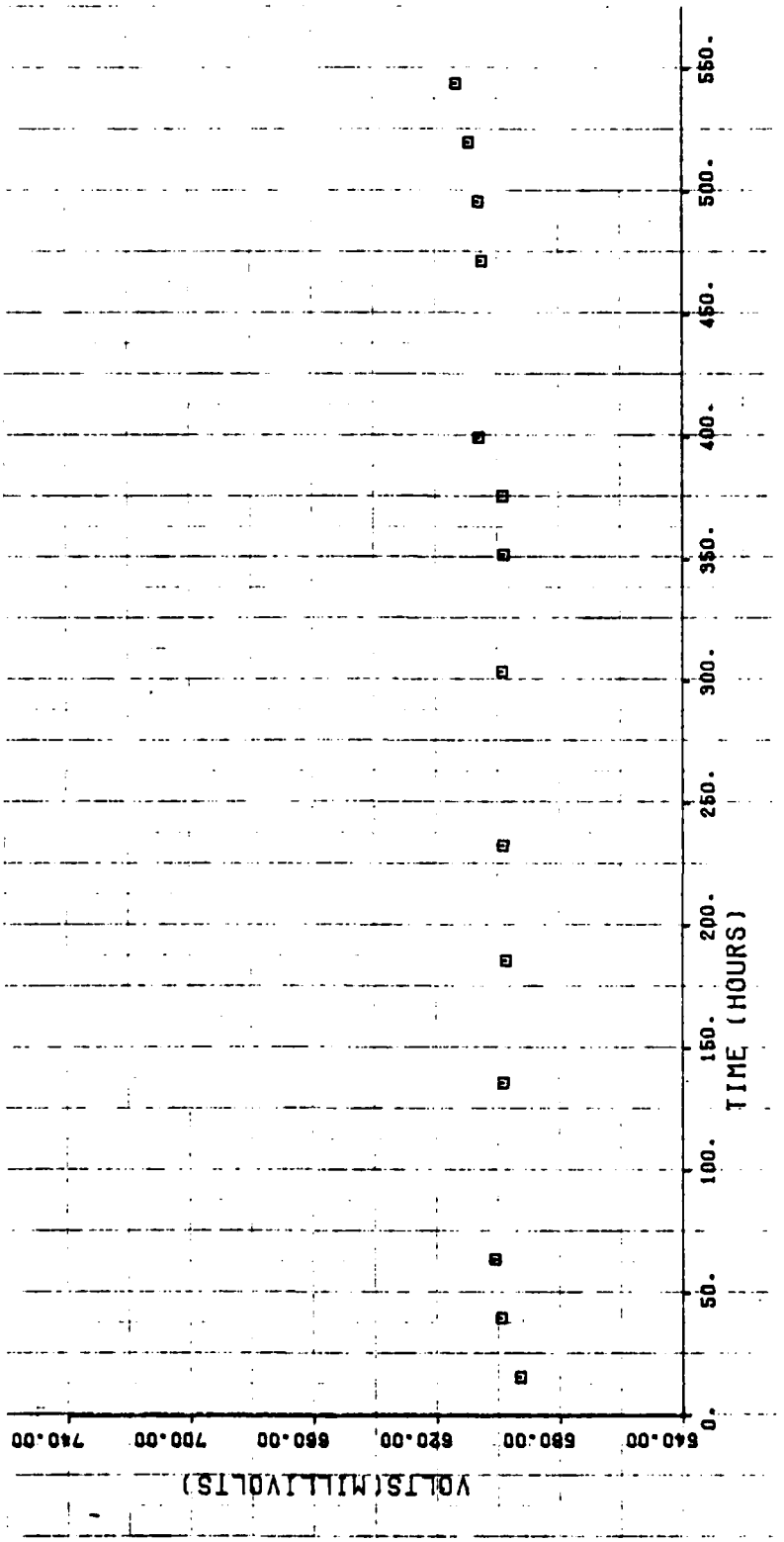


Figure A-4. Performance History of Cell 3406



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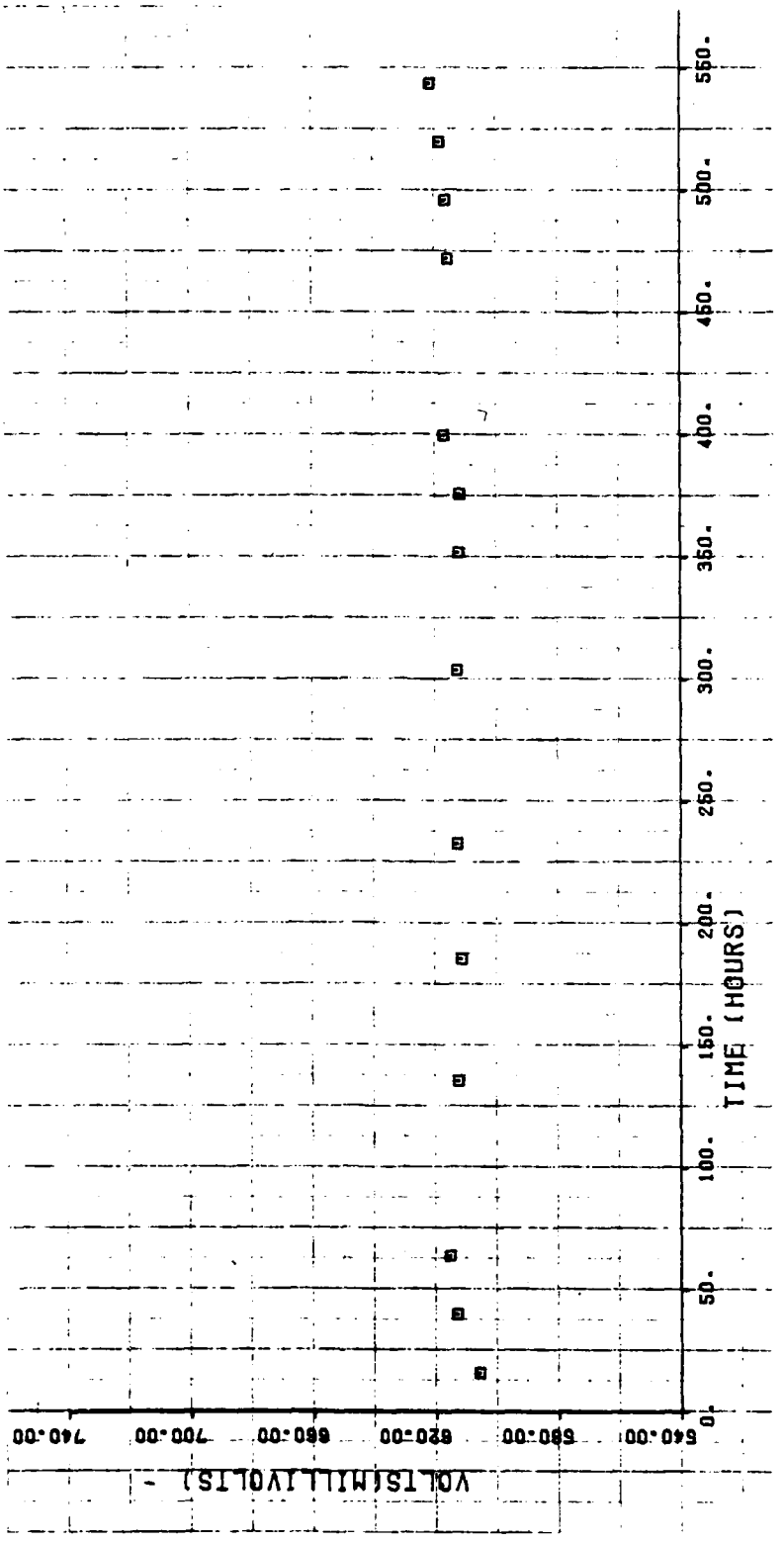

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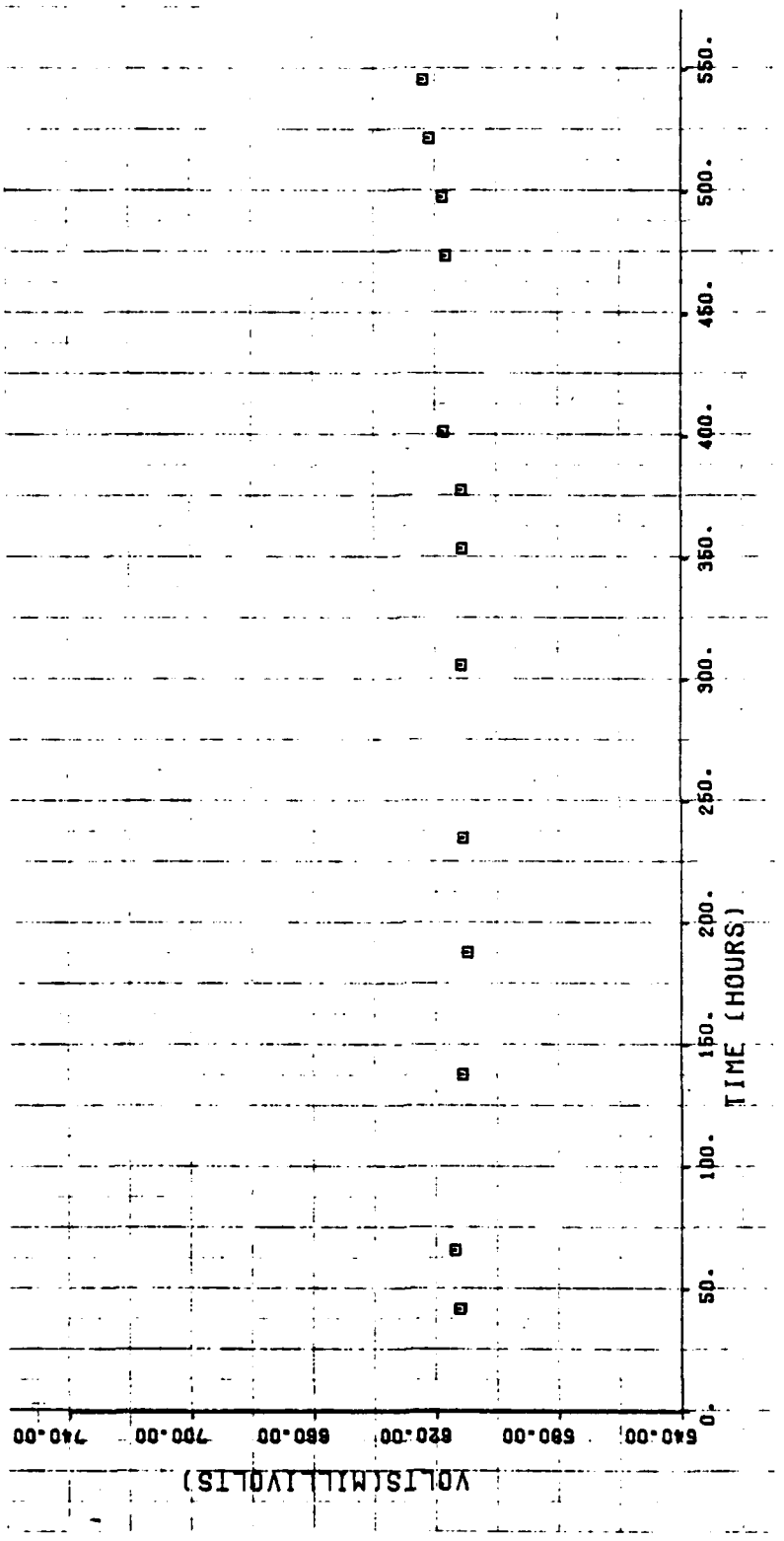

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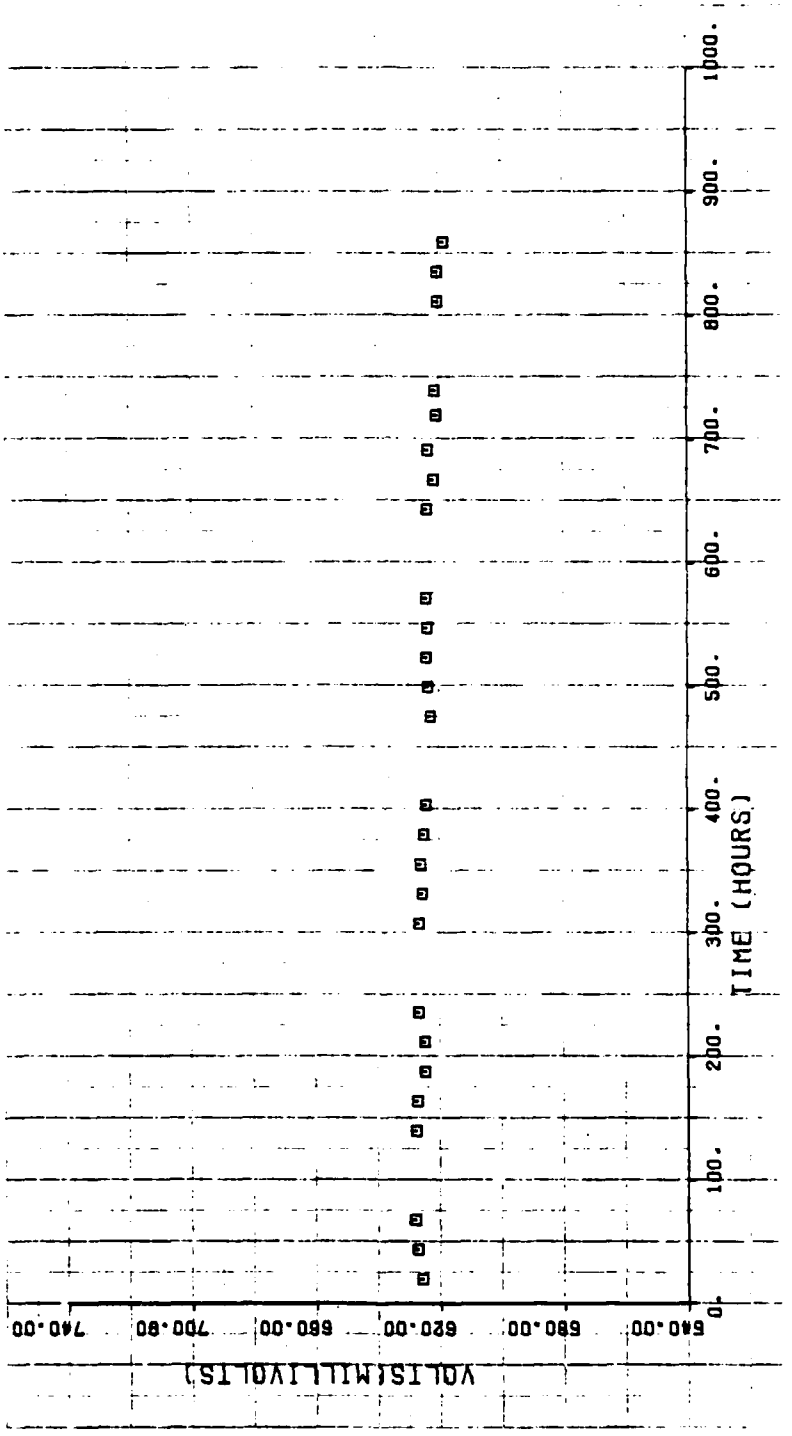

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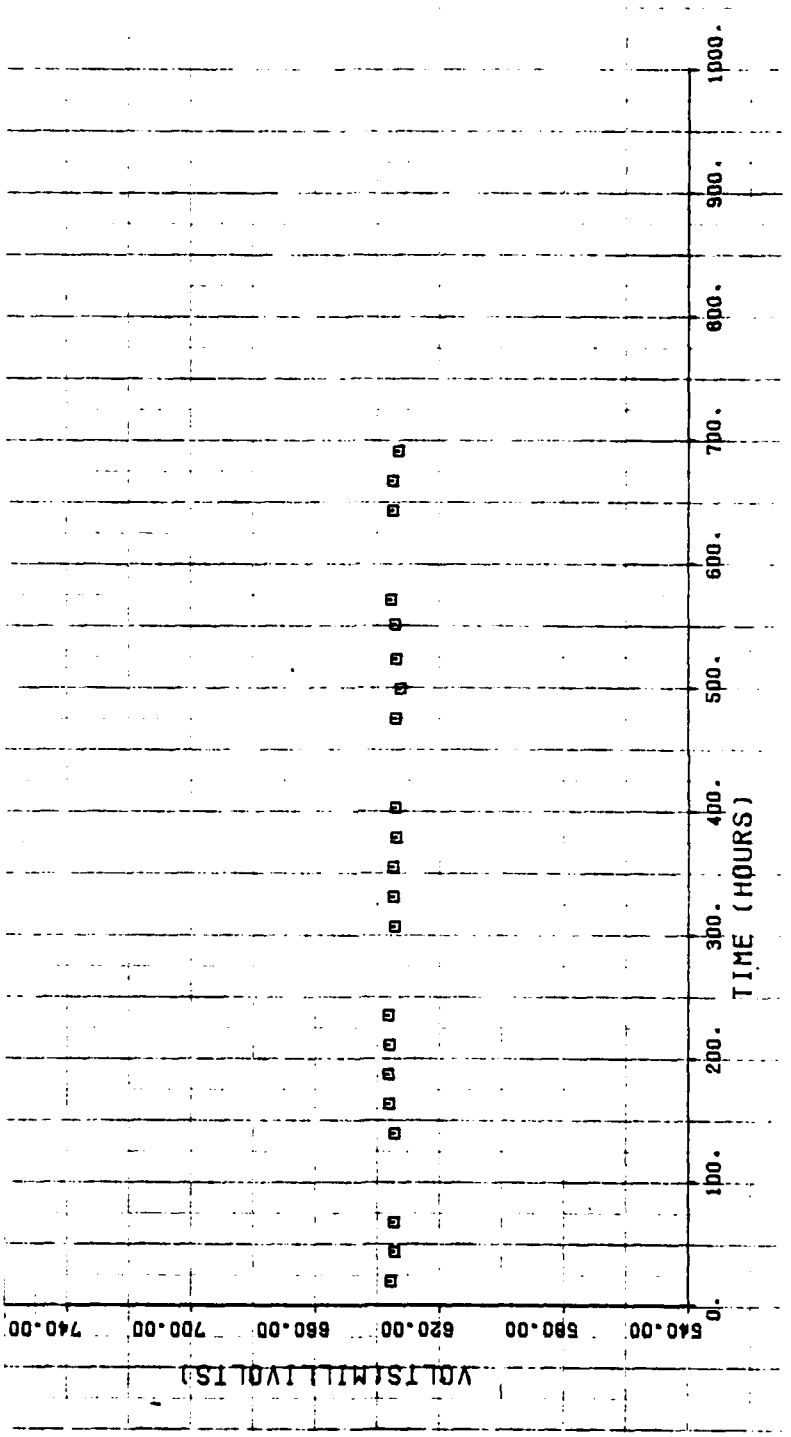

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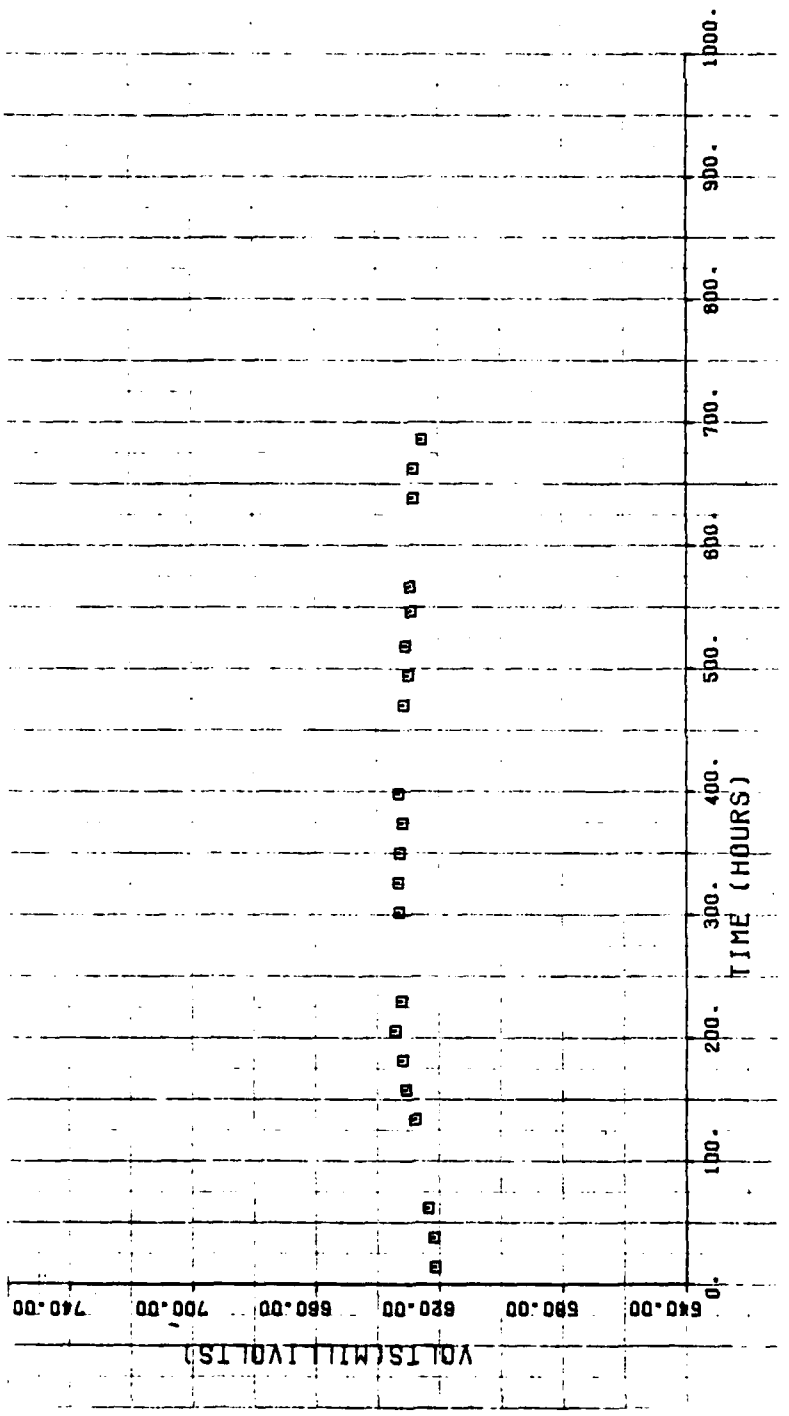

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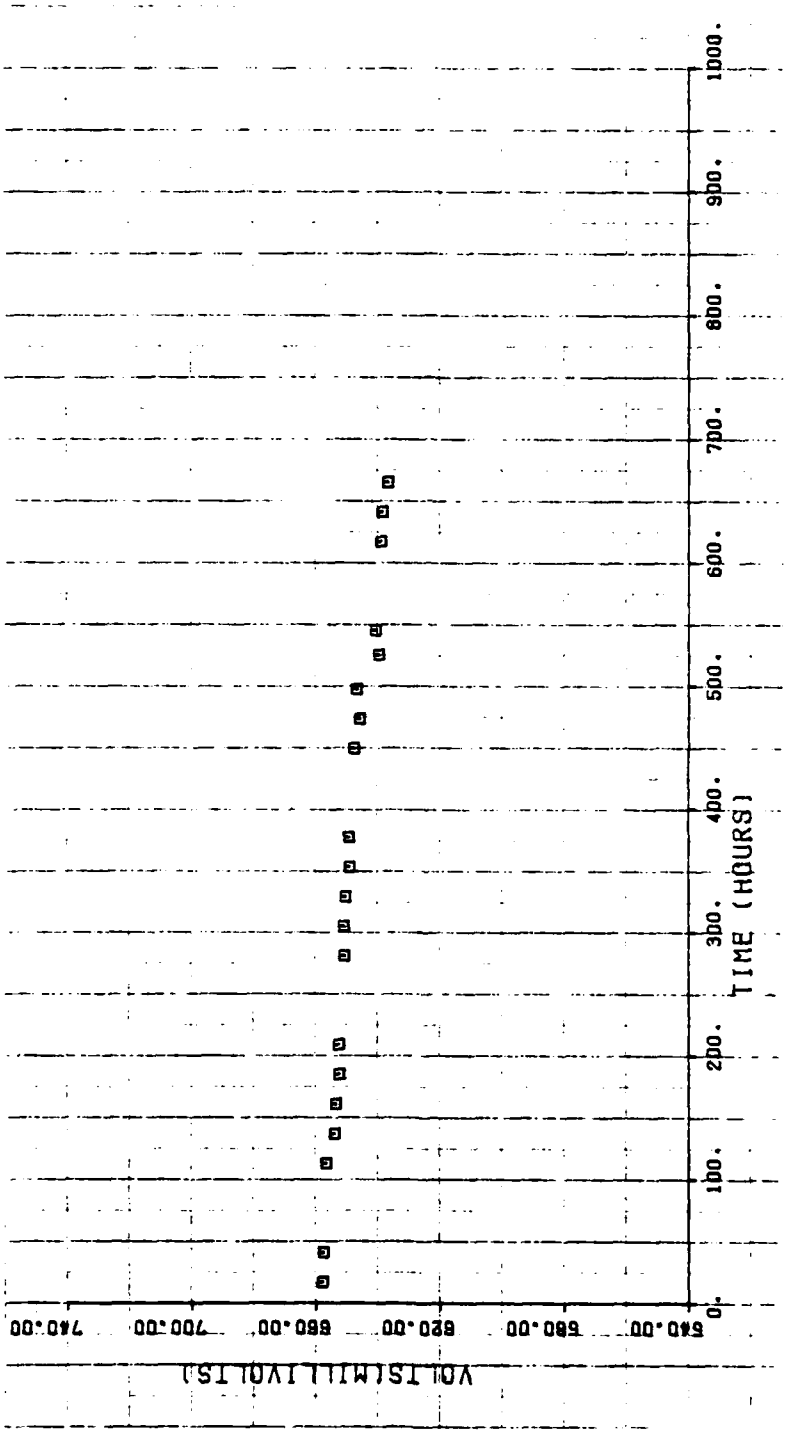

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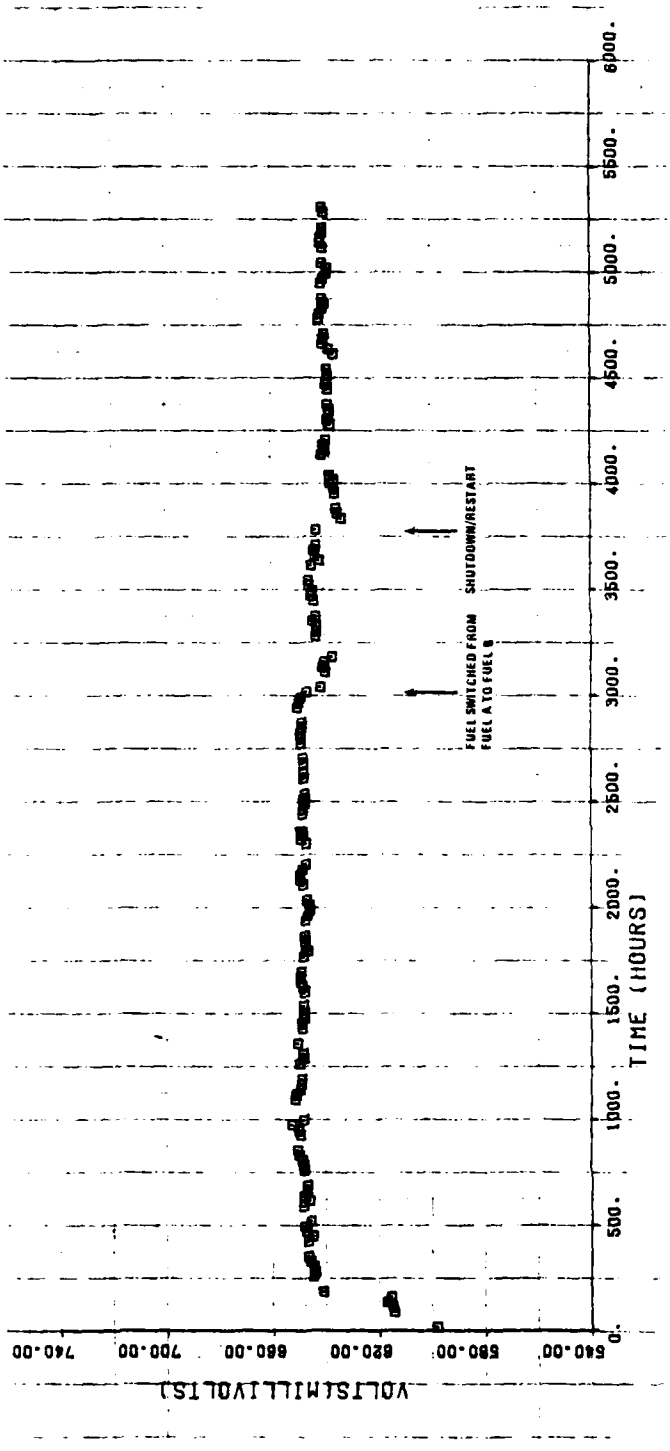
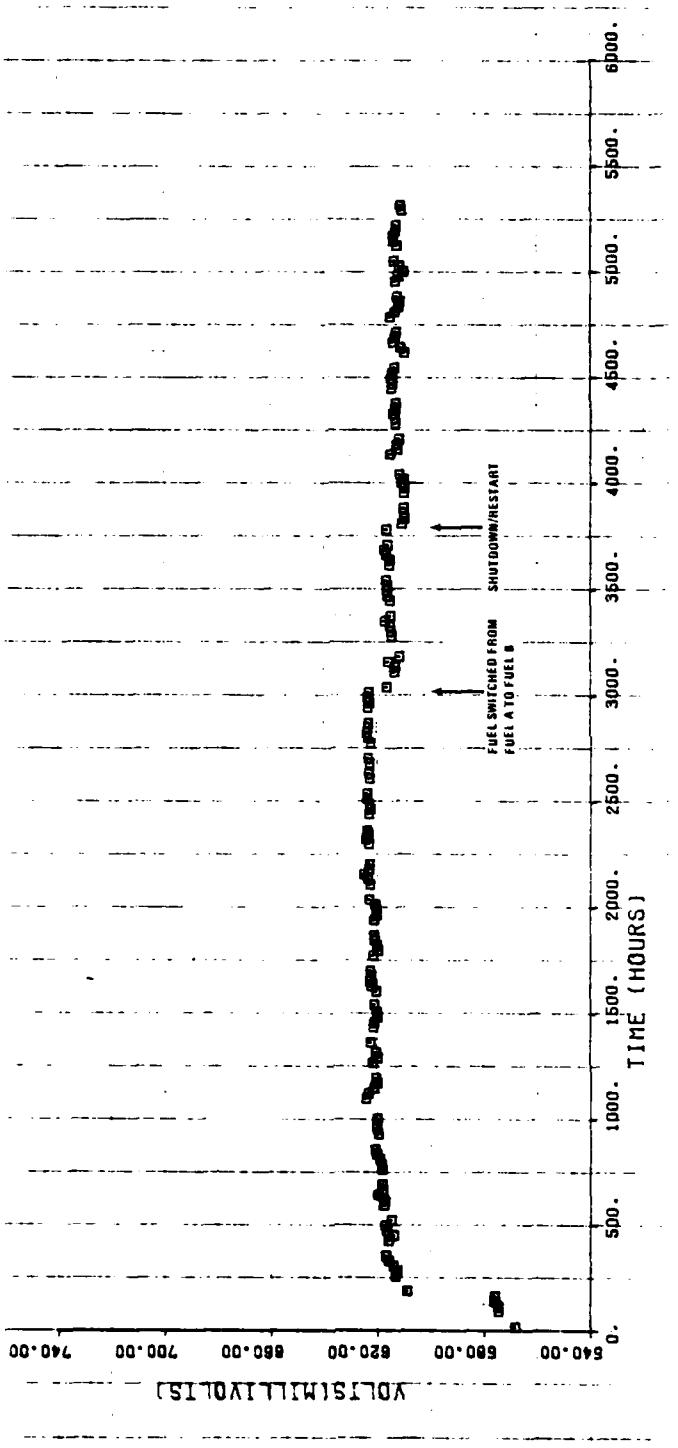


Figure A-12. Performance History of Cell 3418



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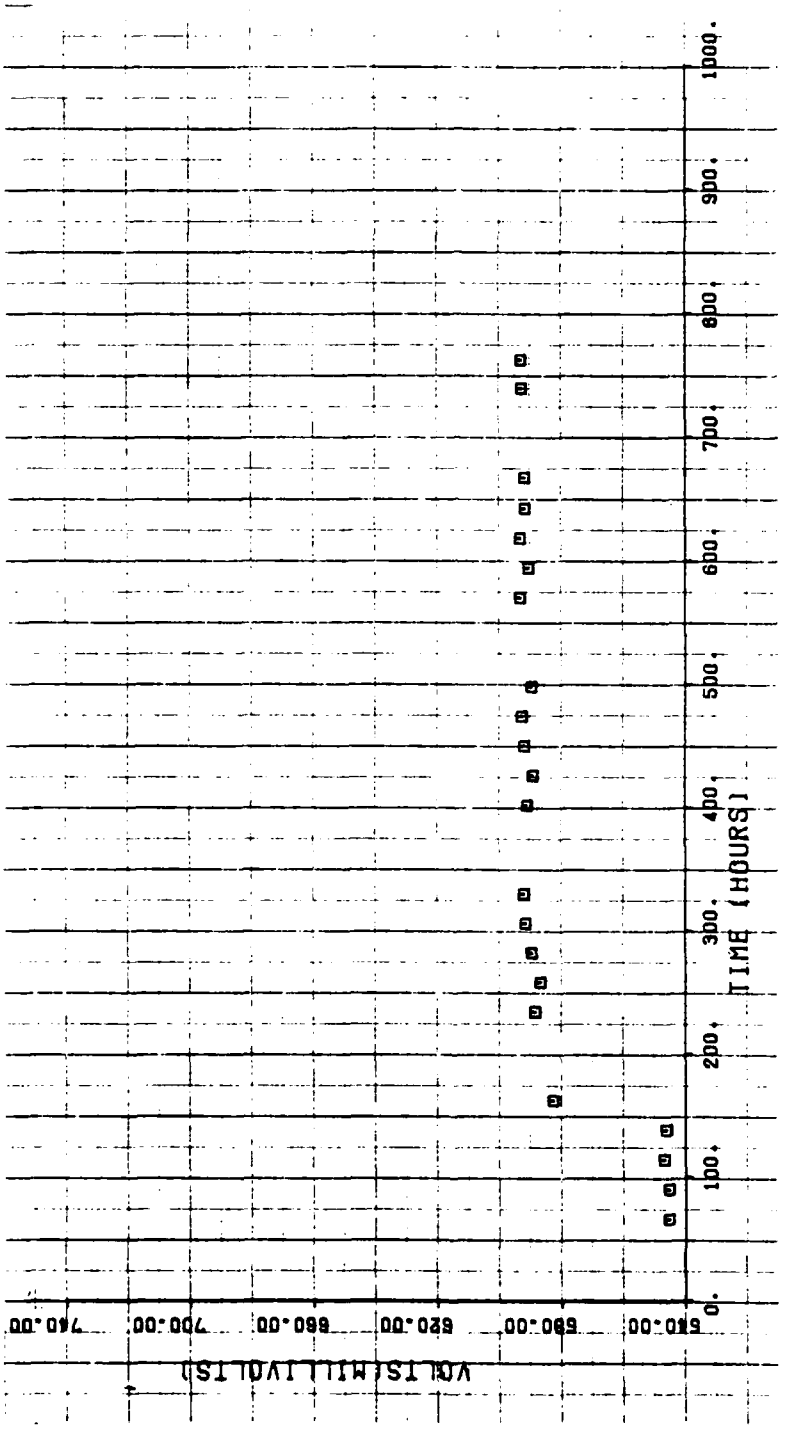

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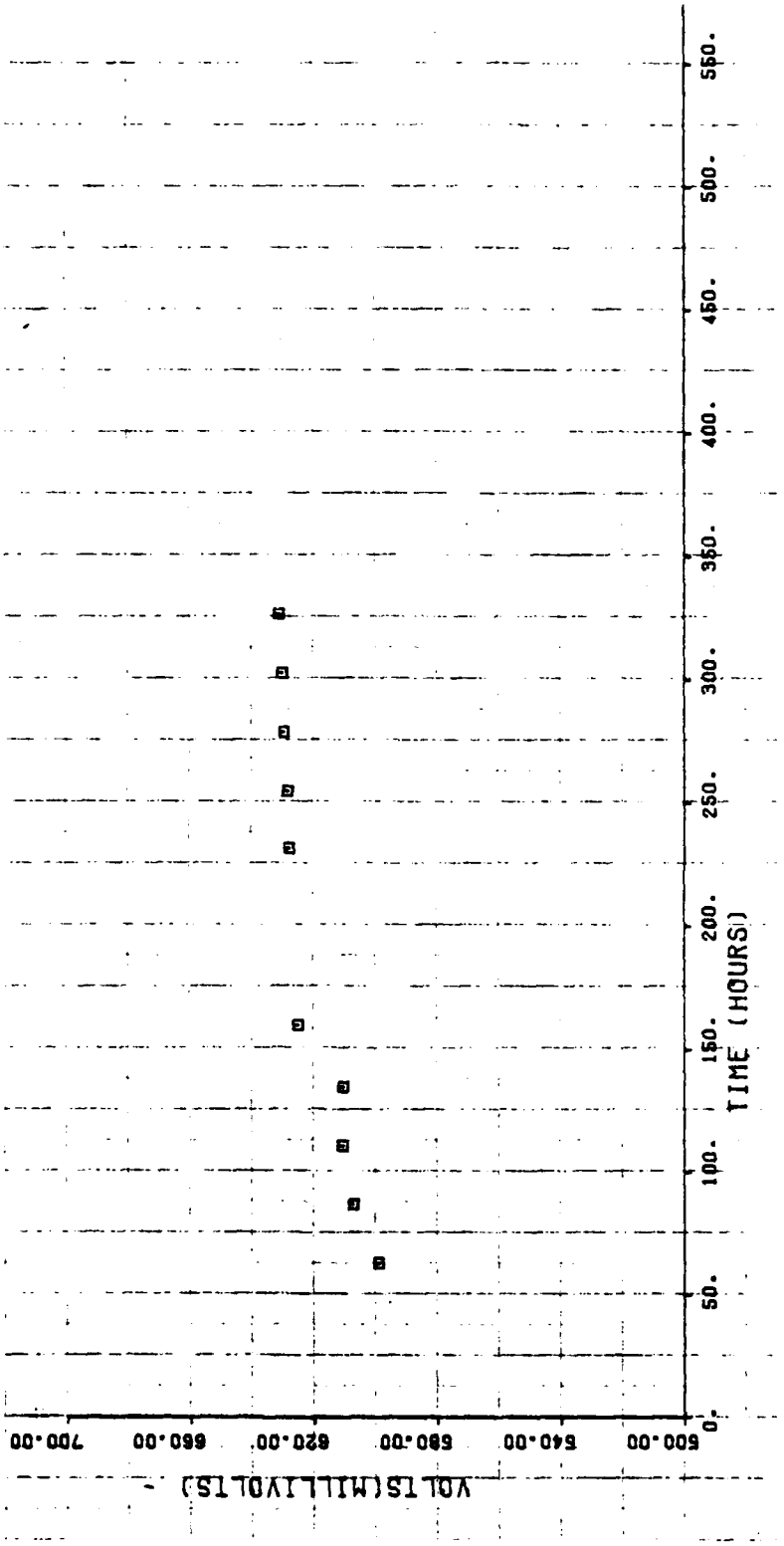

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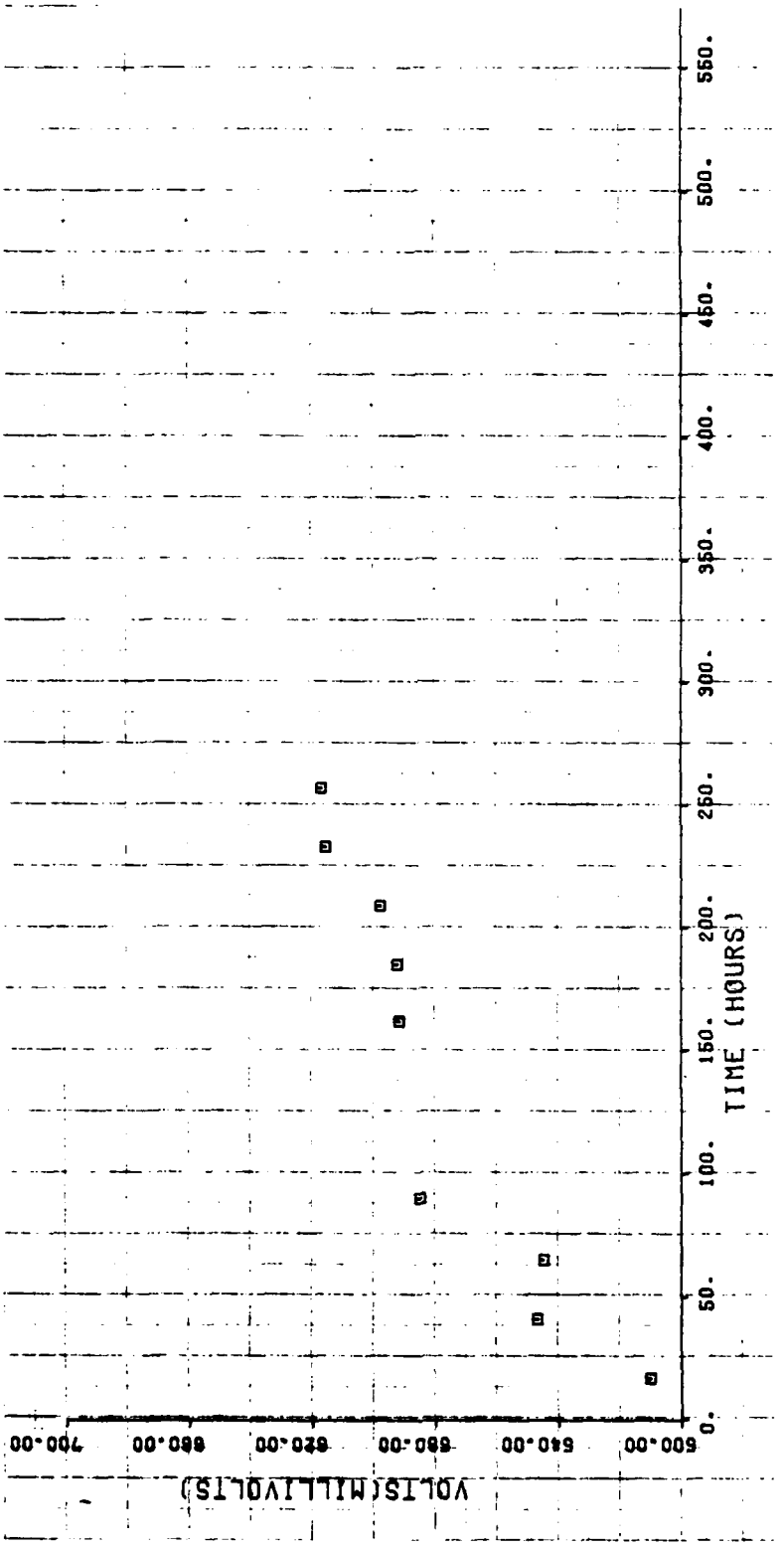

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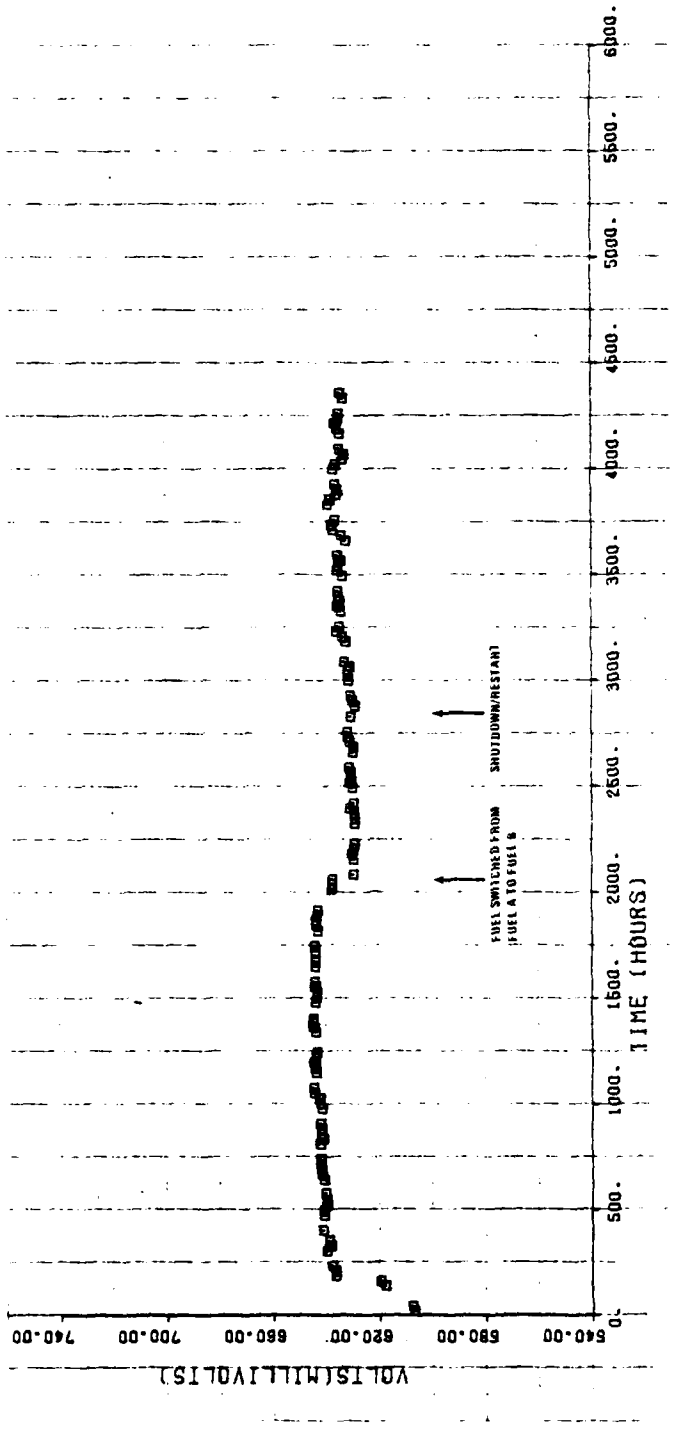

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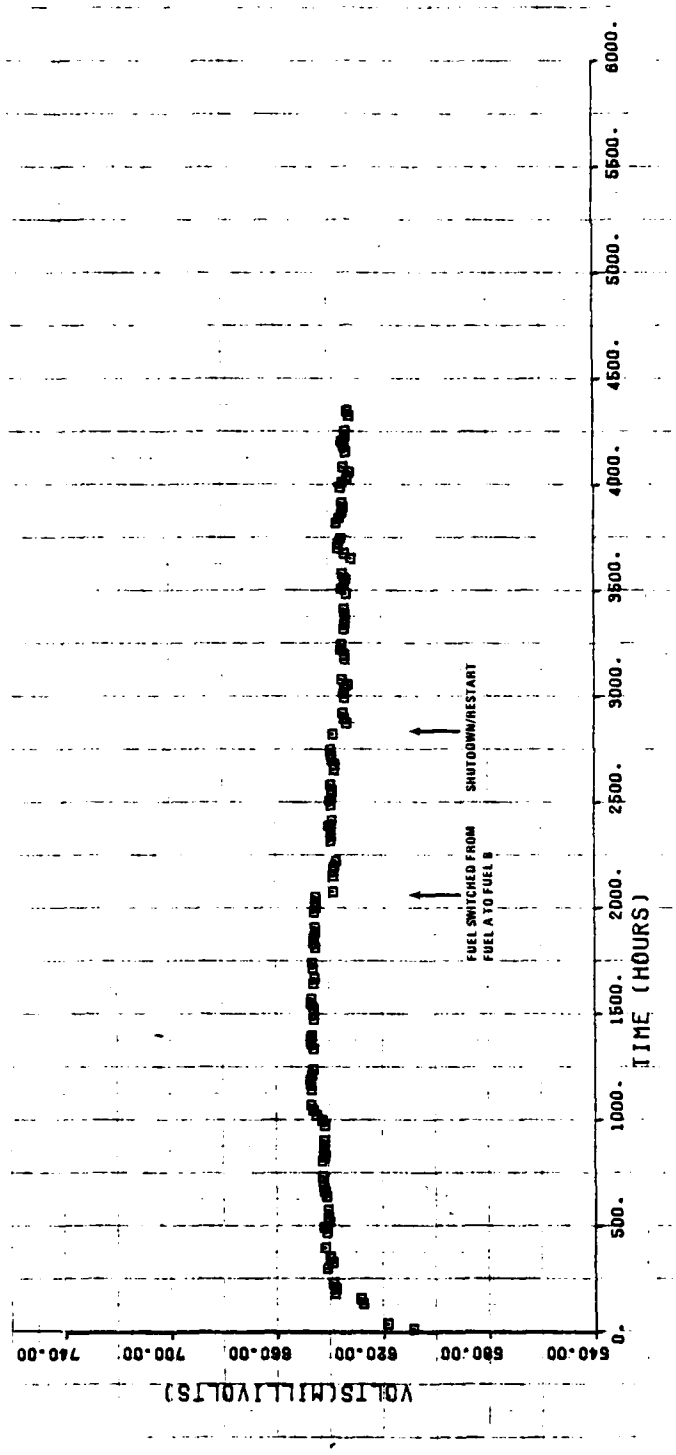

Figure A-18. Performance History of Cell 3424

APPENDIX B

DIAGNOSTIC PERFORMANCE DATA FOR CELLS

TABLE B-1. DIAGNOSTIC PERFORMANCE DATA FOR CELLS 3403, 3404, AND 3405

	CELL 3404			CELL 3404			CELL 3405		
Load time, h	94	500	859	94	500	858	141	500	834
Terminal Cell Voltage, V	0.633	0.634	0.630	0.636	0.634	0.624	0.647	0.645	0.634
Activity @ 0.9V, mA/mg	39	31	28	34	26	25	32	26	25
O_2 Gain at 186 ASF, mV	67	65	71	66	65	71	66	67	74
H_2 Gain at 186 ASF, mV	23	21	21	21	17	18	18	17	17
Cell iR at 186 ASF, mV	41	44	46	44	48	52	39	40	43

TABLE B-2. DIAGNOSTIC PERFORMANCE DATA FOR CELLS WITH SHOP 40% TEFLON CATHODES

	CELL 3406		CELL 3407		CELL 3408		CELL 3409	
Load time, h	5	502	3	503	3	505	3	508
Terminal Cell Voltage, V	0.544	0.581	0.571	0.599	0.590	0.609	0.578	0.613
Activity @ 0.9V, mA/mg	8.4	16.0	13.8	22.0	10.2	25.1	29.7	28.9
O_2 Gain at 186 ASF, mV	77	77	74	76	65	71	71	74
H_2 Gain at 186 ASF, mV	17	22	20	23	21	23	20	20
Cell iR at 186 ASF, mV	49	47	57	60	58	60	56	59

TABLE B-3. DIAGNOSTIC PERFORMANCE DATA FOR CELLS WITH LABORATORY 40% TEFLON CATHODES

	CELL 3412		CELL 3413		CELL 3414		CELL 3415	
Load time, h	5	501	2	524	1	519	2	498
Terminal Cell Voltage, V	0.604	0.611	0.611	0.617	0.607	0.620	0.646	0.635
Activity @ 0.9V, mA/mg	16.8	20.7	11.3	12.6	13.0	16.4	20.8	25.3
O_2 Gain at 186 ASF, mV	77	76	68	75	76	73	64	74
H_2 Gain at 186 ASF, mV	20	31	21	34	21	30	16	30
Cell iR at 186 ASF, mV	55	60	37	40	42	49	39	44

TABLE B-4. DIAGNOSTIC PERFORMANCE DATA FOR LONG-TERM ENDURANCE CELLS

	CELL 3420		CELL 3421	CELL 3422
Load time, h	2	259	2	2
Terminal Cell Voltage, V	0.515	0.584	0.573	0.574
Activity @ 0.9V, mA/mg	10.6	22.1	8.0	7.8
O_2 Gain at 186 ASF, mV	92	75	73	70
H_2 Gain at 186 ASF, mV	25	27	17	22
Cell iR at 186 ASF, mV	43	43	28	29

TABLE B-5. DIAGNOSTIC PERFORMANCE DATA FOR LONG-TERM ENDURANCE CELLS

	CELL 3418							CELL 3419						
Load time, h	1	280	1000	2010	2991	4040	4998	1	284	1004	2014	2995	4044	5002
Terminal Cell Voltage at 186 ASF, V	0.567	0.635	0.639	0.637	0.639	0.630	0.627	0.529	0.610	0.618	0.620	0.620	0.610	0.610
Terminal Cell Voltage at 93 ASF, V	----	----	----	0.697	0.697	0.686	0.686	----	----	----	0.690	0.687	0.674	0.675
Activity @ 0.9V, mA/mg	14.4	32.7	26.5	23.8	20.4	17.9	14.5	13.7	30.4	24.6	22.9	19.9	17.2	13.9
O_2 Gain at 186 ASF, mV	74	70	72	72	71	74	73	86	73	73	72	71	76	71
H_2 Gain at 186 ASF, mV	21	23	21	21	21	26	28	29	27	24	26	27	35	34
Cell iR at 186 ASF, mV	32	32	31	32	31	31	31	38	37	36	36	35	36	35

	CELL 3423						CELL 3424					
Load time, h	2	165	1007	2012	3179	4020	2	161	1003	2008	3175	4016
Terminal Cell Voltage at 186 ASF, V	0.541	0.619	0.644	0.638	0.633	0.636	0.543	0.628	0.645	0.645	0.635	0.634
Terminal Cell Voltage at 93 ASF, V	----	----	0.699	0.693	0.690	0.691	----	----	0.700	0.700	0.691	0.691
Activity @ 0.9V, mA/mg	6.7	21.2	19.2	11.4	12.0	11.0	9.9	23.2	20.2	16.6	13.3	11.3
O_2 Gain at 186 ASF, mV	78	71	72	72	75	73	79	74	75	75	77	76
H_2 Gain at 186 ASF, mV	14	18	17	21	26	24	15	17	19	21	26	27
Cell iR at 186 ASF, mV	24	23	23	22	22	22	25	24	23	23	23	23

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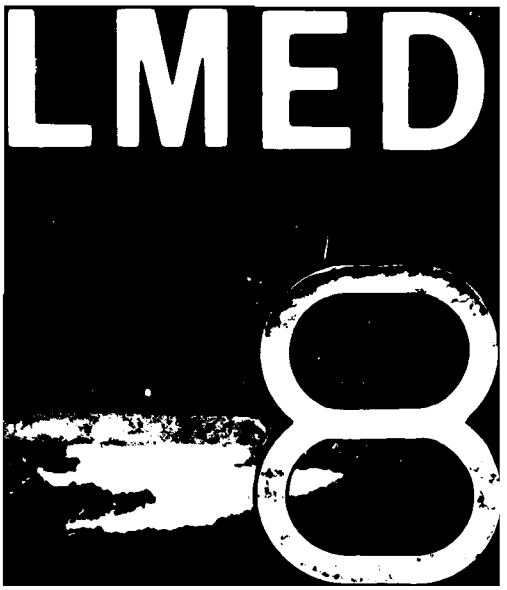
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